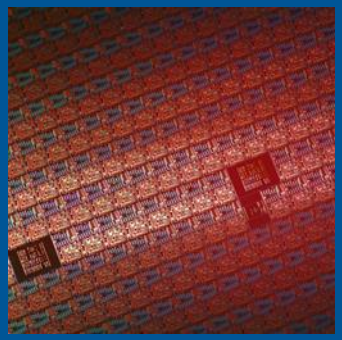
Accelerating the next technology revolution

Enabling robust EUV lithography for NXE3300 applications

2013 SEMATECH's Cycles Of Learning Project Combined with TEL

Jun Sung Chun[a,c], Shih-Hui Jen[a] , Karen Petrillo[a], Dominic Ashworth[a], Mark Neisser[a], Takashi Saito[b] , Lior Huli[b] , David Hetzer[b]

[a] SEMATECH, Albany Nanotech, Albany, NY 12203
[b] TEL Technology Center, America, LLC, Albany Nanotech, Albany NY 12203
[c] CNSE of SUNY, Albany Nanotech, Albany, NY 12203



Agenda

- 2013 Cycle Of Learning (COL) Summary
- Under Layer (UL) evaluation
- Resists evaluation for L/S
- FIRM™ rinse, Track Based Smoothing study

2013 for Cycle Of Learning (COL)

	L/S COL	C/H COL	UL COL	Shifts in BMET
May			2	**2**
June	3.5			**3.5**
July	0.5	3	2(re-run)	**5.5**
Aug.		0.5		**0.5**
Sept.	1.5	0.5		**2**
Oct.	1.5	0.5		**2**
Nov.		2	2	**4**
Dec.	1			**1**
Total	8	6.5	6	20.5

@ AMET was used, EUV resist was SEMATECH POR

@ Currently on schedule,

- Finished UL and L/S : be published at 2013 EUV Symposium
- Finishing Contact hole : be published at 2014 SPIE
- Started second round of COL

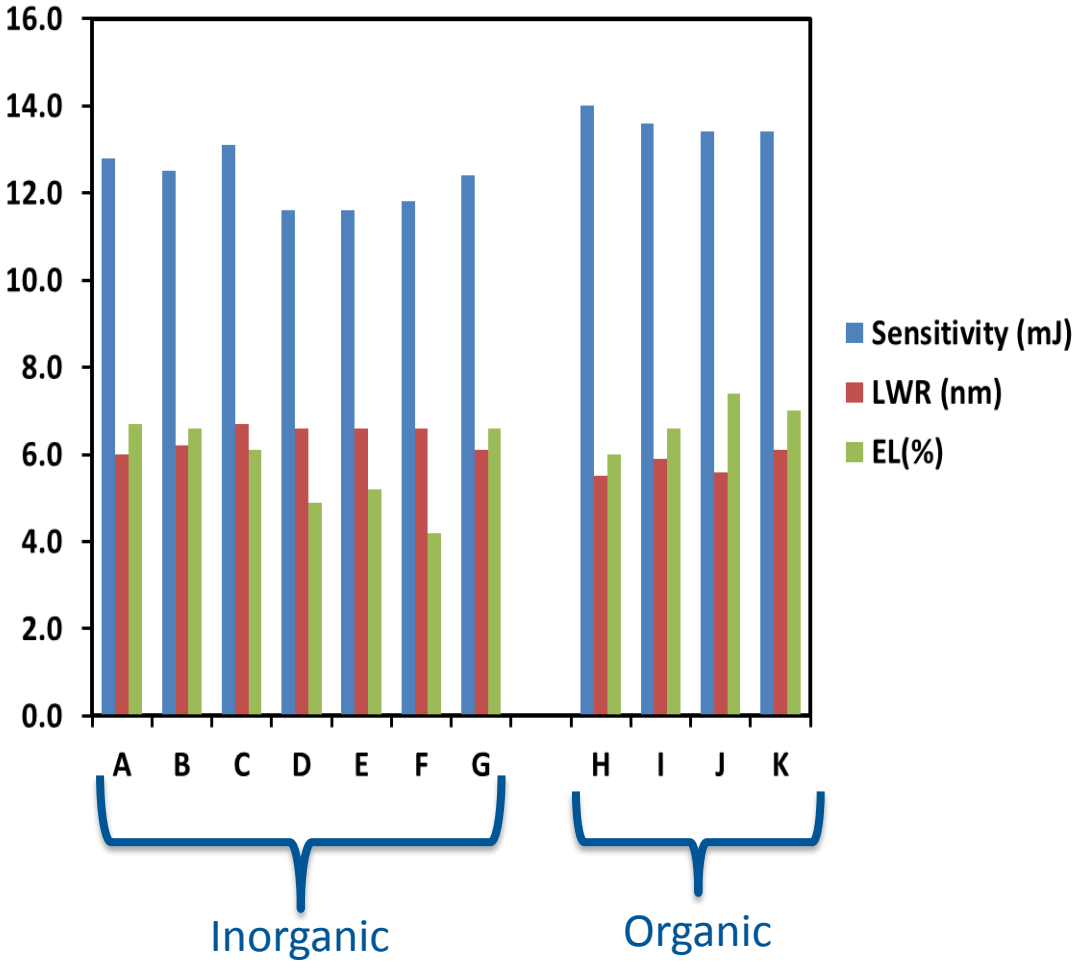
- **Under-Layers**

Protocol for Under-Layer Evaluation

1. SEMATECH POR resist
2. Pattern Collapse comparison at 26nm
3. Sensitivity
4. LWR (Line Width Roughness)
5. EL (Exposure Latitude)
6. Top down and X-section profile

UL Evaluation

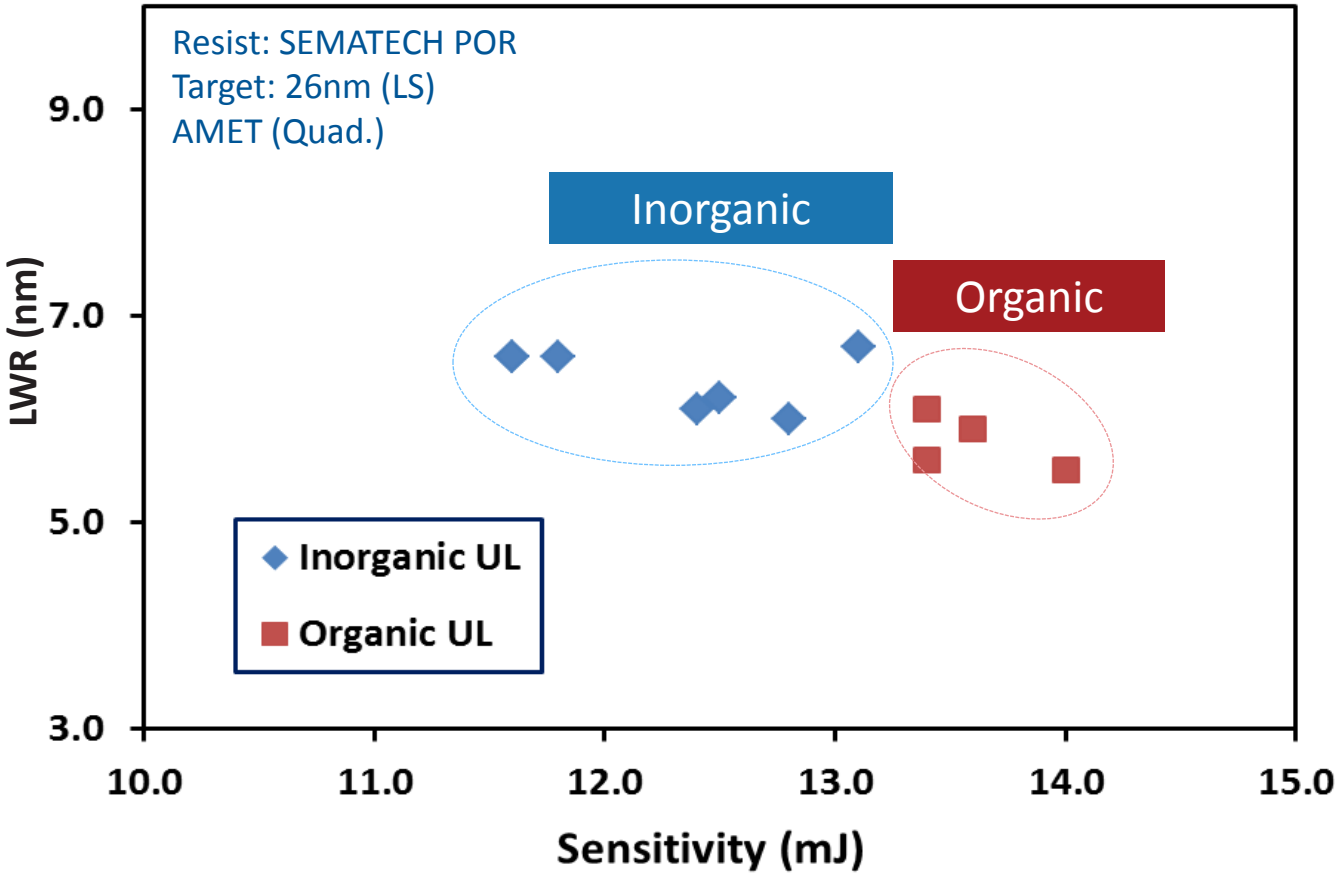
Resists	Sensitivity (mJ)	LWR (nm)	EL (%)
	Inorganic UL		
A	12.8	6.0	6.7
B	12.5	6.2	6.6
C	13.1	6.7	6.1
D	11.6	6.6	4.9
E	11.6	6.6	5.2
F	11.8	6.6	4.2
G	12.4	6.1	6.6
	Organic UL		
H	14.0	5.5	6.0
I	13.6	5.9	6.6
J	13.4	5.6	7.4
K	13.4	6.1	7.0



Resist: SEMATECH POR
Target: 26nm (LS)
AMET (Quad.)

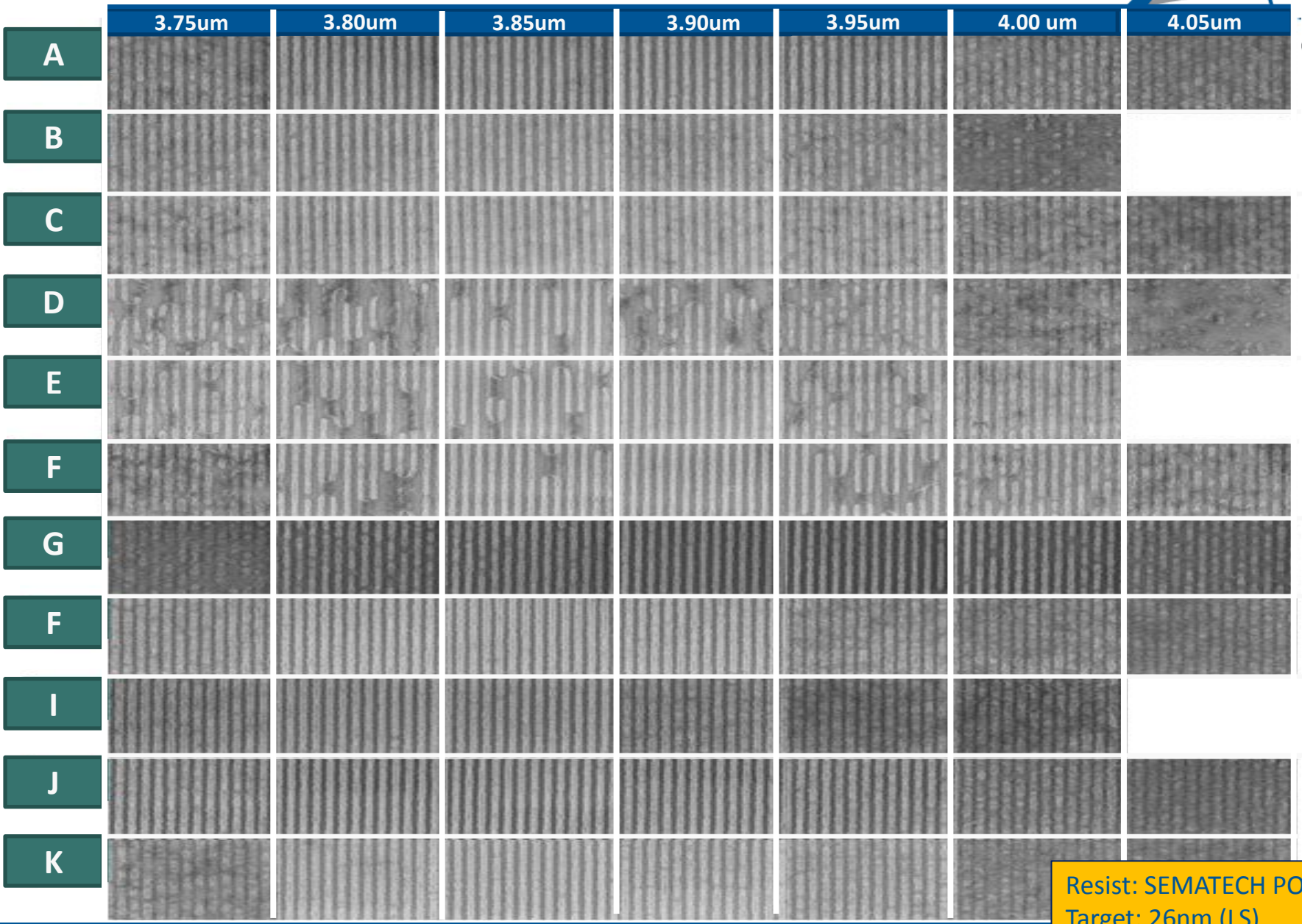
UL Evaluation

LWR vs. Sensitivity



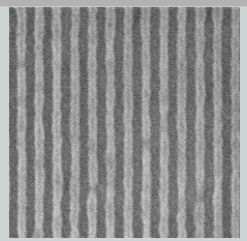
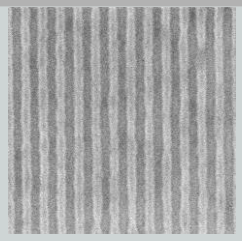
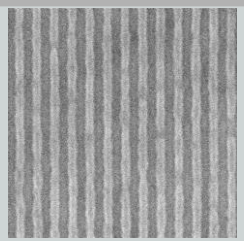
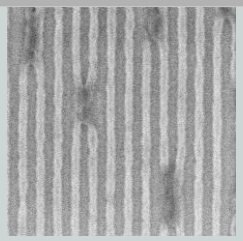
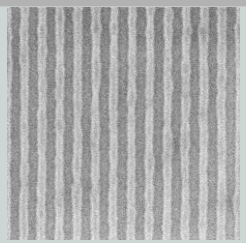
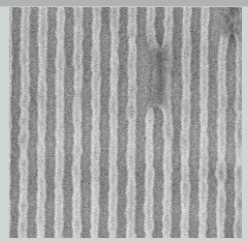
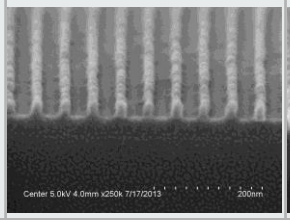
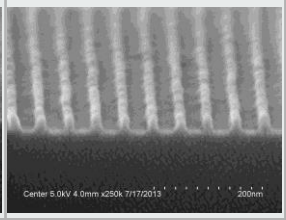
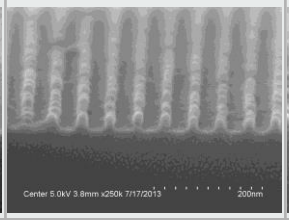
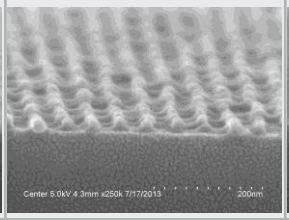
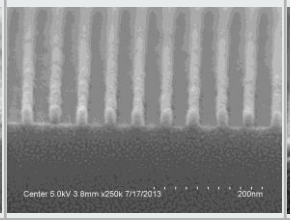
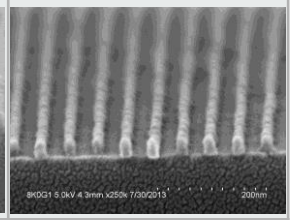
- **Organic ULs show better LWR however with higher sensitivity**
- **Inorganic ULs show lower sensitivity**

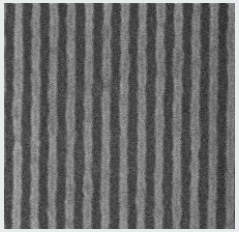
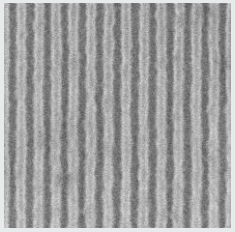
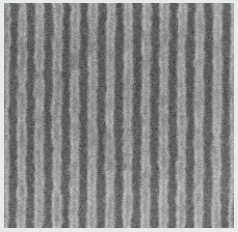
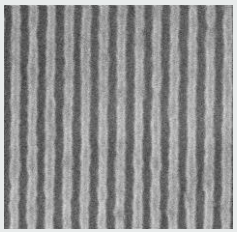
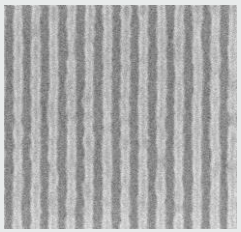
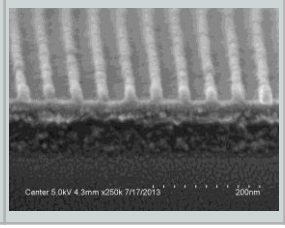
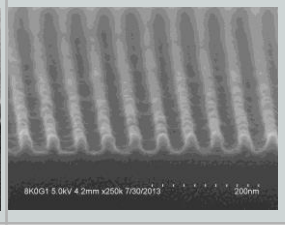
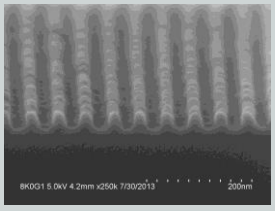
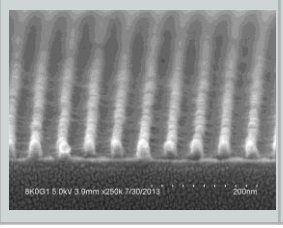
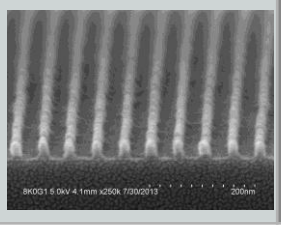
Top-downs, 26nm thru-focus at best dose



Resist: SEMATECH POR
Target: 26nm (LS)
AMET (Quad.)

Patterning Images, Best Focus

	A	B	C	D	F	F
Top down						
X-section						

	G	H	I	J	K	
Top down						
X-section						

Resist:
SEMATECH POR
Target: 26nm (LS)
AMET (Quad.)

Summary, Under-Layer Evaluation

1. Organic underlayers tend to show higher sensitivity and **better LWR**

2. Inorganic underlayers tend to show **better sensitivity** but worse LWR

3. Profiles on different ULs were comparable in quality except for 3 inorganic ULs which had a lot of line collapse

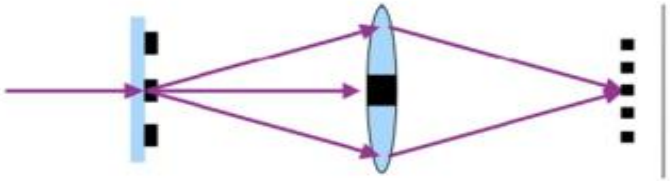
- **Resist materials, Line and Space**

2013 COL Protocol, EUV Resists Evaluation

Initial screening

- Resolution : select resists that have at least than 20 nm resolution

Berkeley MET
Illumination: Pseudo PSM F2X
Mask: IMO228775



Pseudo PSM

Acquire data for resists that pass the first screening

- Sensitivity
- EL
- LWR/LER
- Minimum resolution

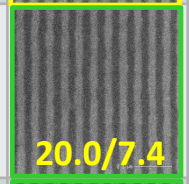
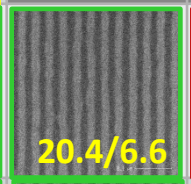
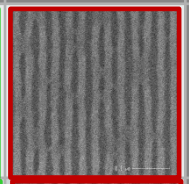
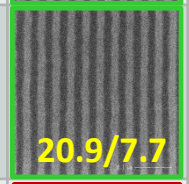
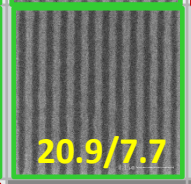
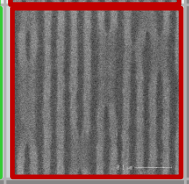
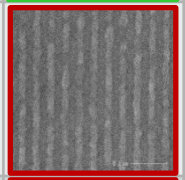
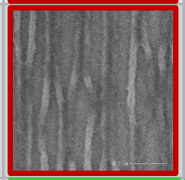
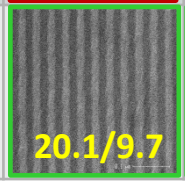
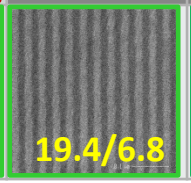
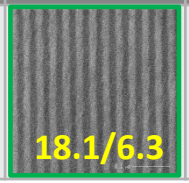
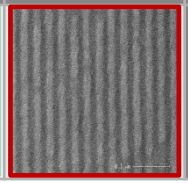
3rd screening-final

- Outgas test

Process Conditions, Line and Spaces

1. **6 resist suppliers participated**
2. **18 EUV resist evaluated**
3. **3 different UL used**
4. **Resist Thickness used was 30nm or 35 nm**
5. **One resist supplier requested to use BMAH, 0.26N**
6. **One resist supplier requested to use FIRM process**

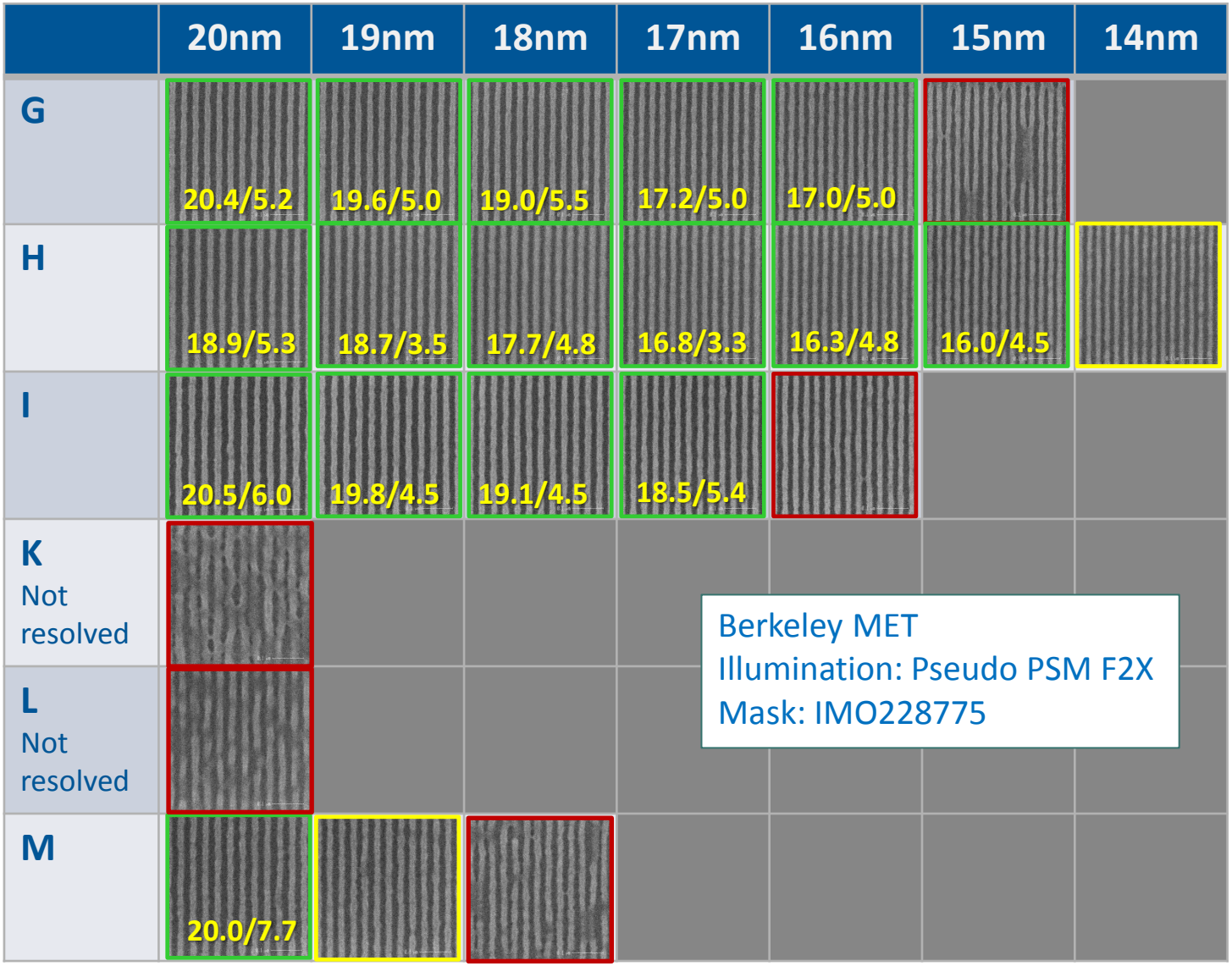
Most Recent LS Results, BMET

	20nm	19nm	18nm	17nm	16nm	15nm	14nm
A	 23.0/7.6						
B	 20.0/7.4	 20.4/6.6					
C	 20.9/7.7	 20.9/7.7					
D Not resolved							
E Not resolved							
F	 20.1/9.7	 19.4/6.8	 18.1/6.3				

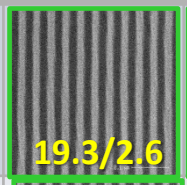
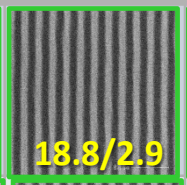
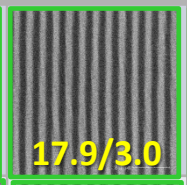
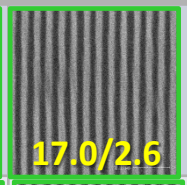
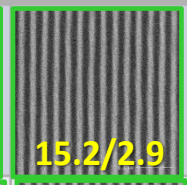
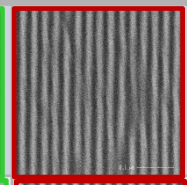
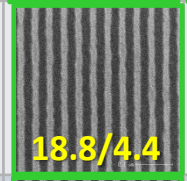
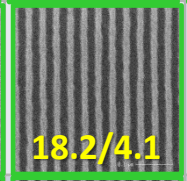
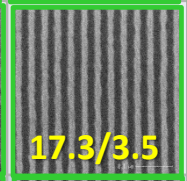
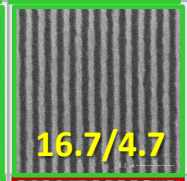
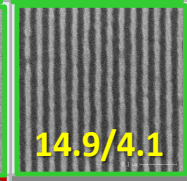
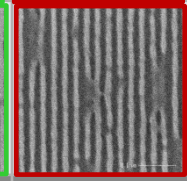
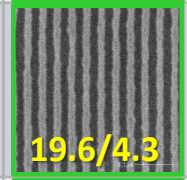
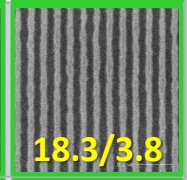
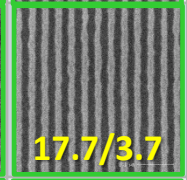
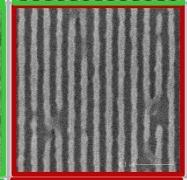
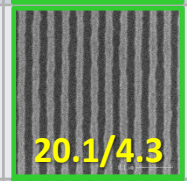
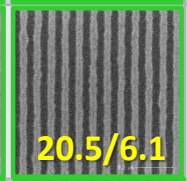
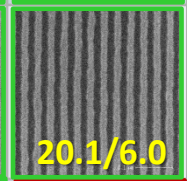
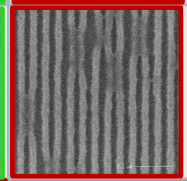
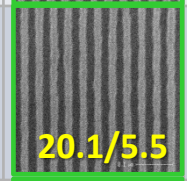
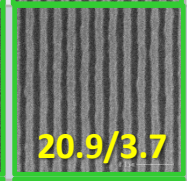
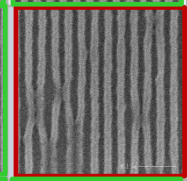
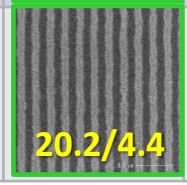
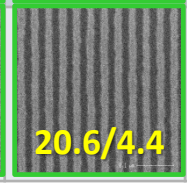
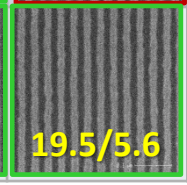
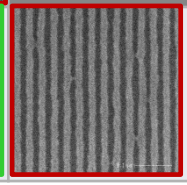
Berkeley MET
Illumination: Pseudo PSM F2X
Mask: IMO228775

Dose[mJ/sqcm]/
LWR [nm]

Most Recent LS Results, BMET



Most Recent LS Results, BMET

	20nm	19nm	18nm	17nm	16nm	15nm	14nm
M	 19.3/2.6	 18.8/2.9	 17.9/3.0	 17.0/2.6	 15.2/2.9		
N	 18.8/4.4	 18.2/4.1	 17.3/3.5	 16.7/4.7	 14.9/4.1		
O	 19.6/4.3	 18.3/3.8	 17.7/3.7				
P	 20.1/4.3	 20.5/6.1	 20.1/6.0				
Q	 20.1/5.5	 20.9/3.7					
R	 20.2/4.4	 20.6/4.4	 19.5/5.6				

Dose[mJ/sqcm]/
LWR [nm]

Summary Table for Results

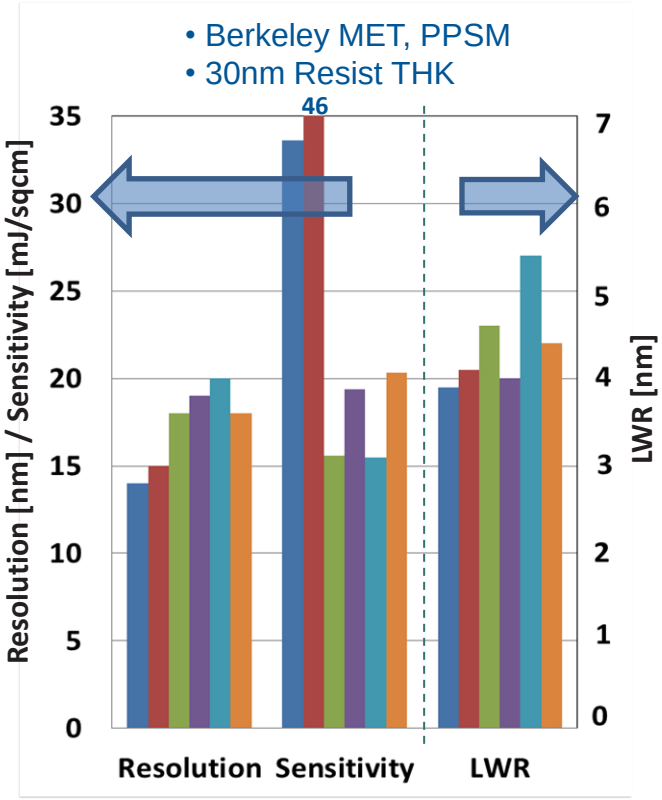
	Resolution [nm]	Sensitivity [mJ]	EL [%]	LWR [nm]	LER [nm]
A	×				
B	19	28.7	9.5	7	3.6
C	19	42.3	14.3	7.5	3.4
D	×				
E	×				
F	18	35.2	7	9.5	4.8
G	16	50.5	8.3	5.4	2.8
H	15	46.3	11.6	5.2	2.7
I	17	27.8	13.1	5	2.9
J	×				
K	×				
L	20	30	8.2	8.2	4
M	16	22.6	14.1	3.1	1.9
N	16	25.9	12.5	4.1	2.5
O	18	30	6.1	4.8	3
P	18	43.7	5.4	4.8	3
Q	19	49.4	5.8	5.2	2.9
R	18	41	9.8	4.8	3.3

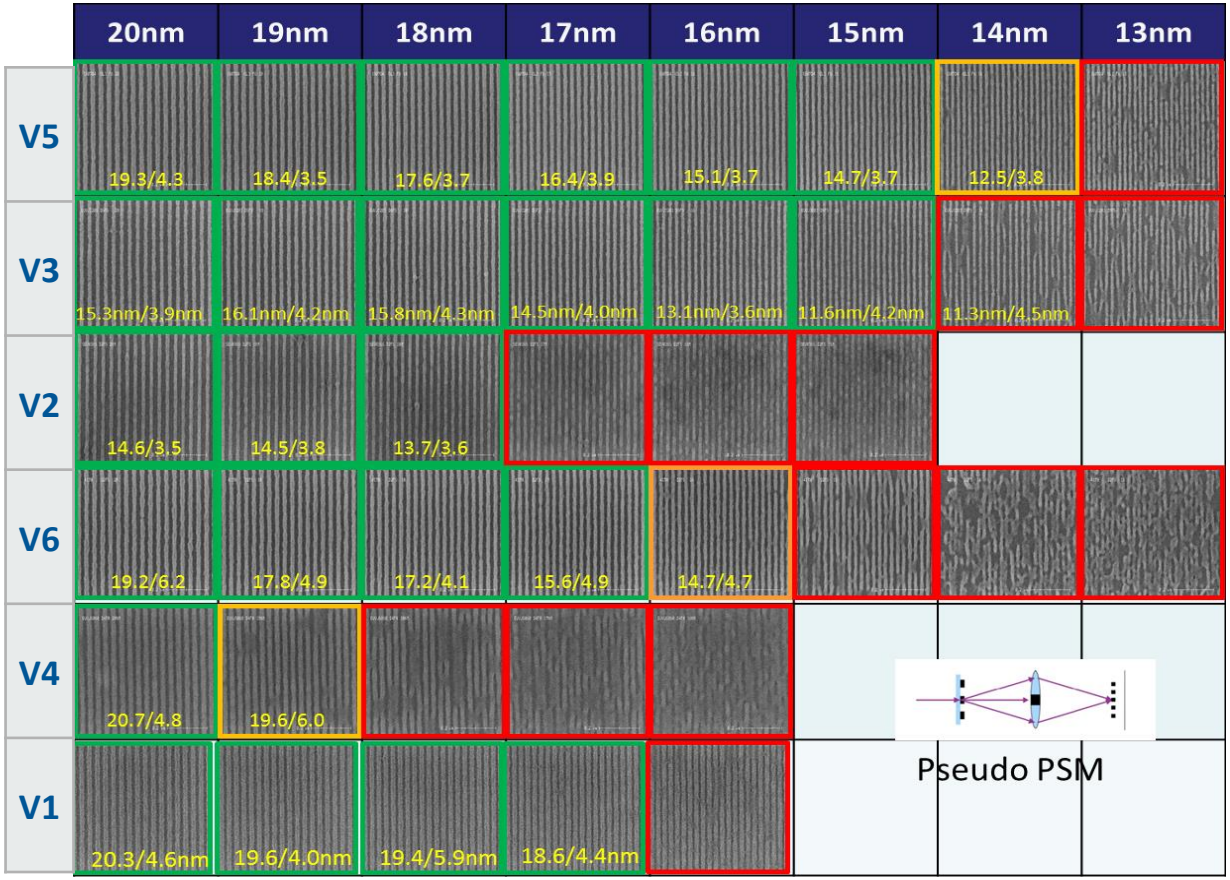
- **Best resolution resist shows 15nm hp, w/ 46.3mJ sensitivity.**
- **Resist w/ lowest Z-factor has lowest LER.**
- **H,M,R were used for further Rinse process with TEL**

Resist Performance Status

Pseudo PSM @ LBNL

Best resolution resist from each supplier

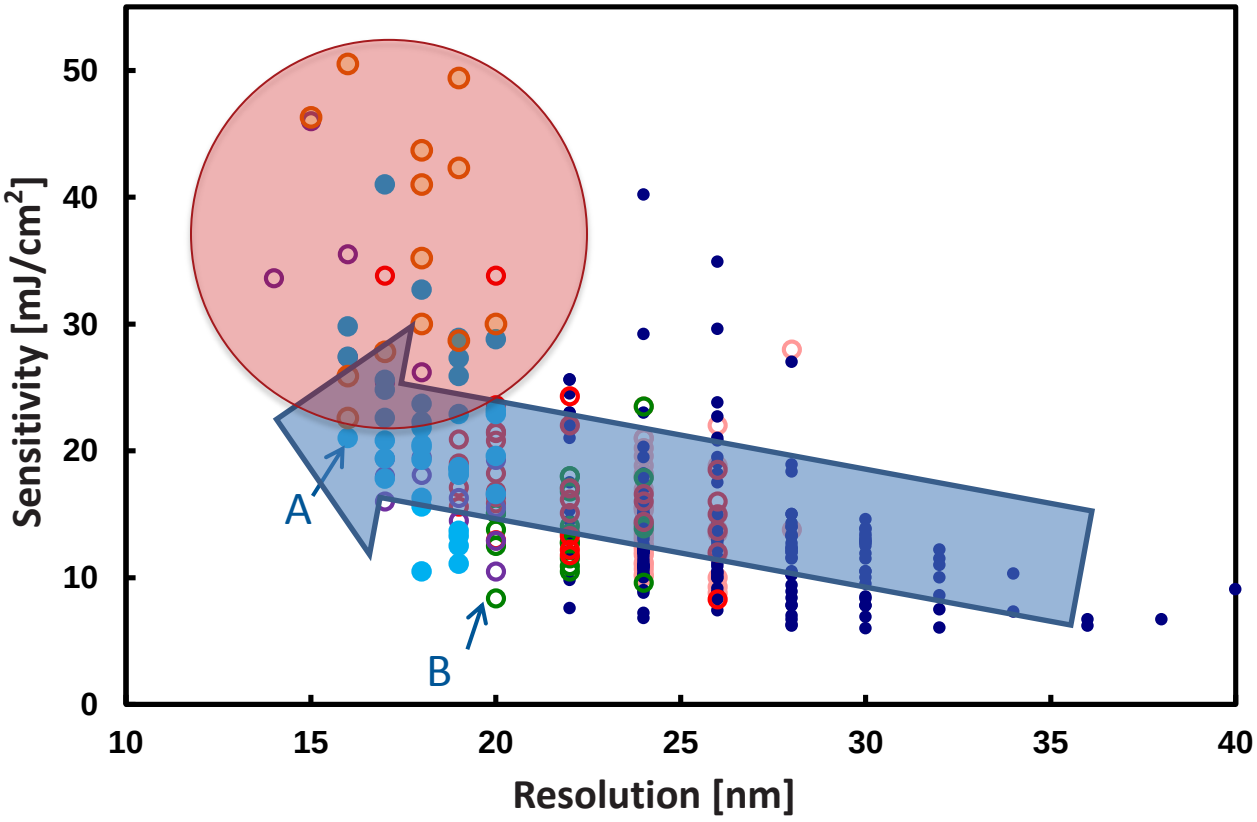


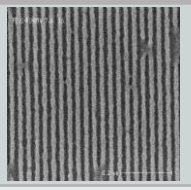
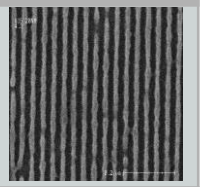


No resist suppliers showed progress in improving resolution compared to previous year

EUV Resist Performance Status

Sensitivity vs. Resolution

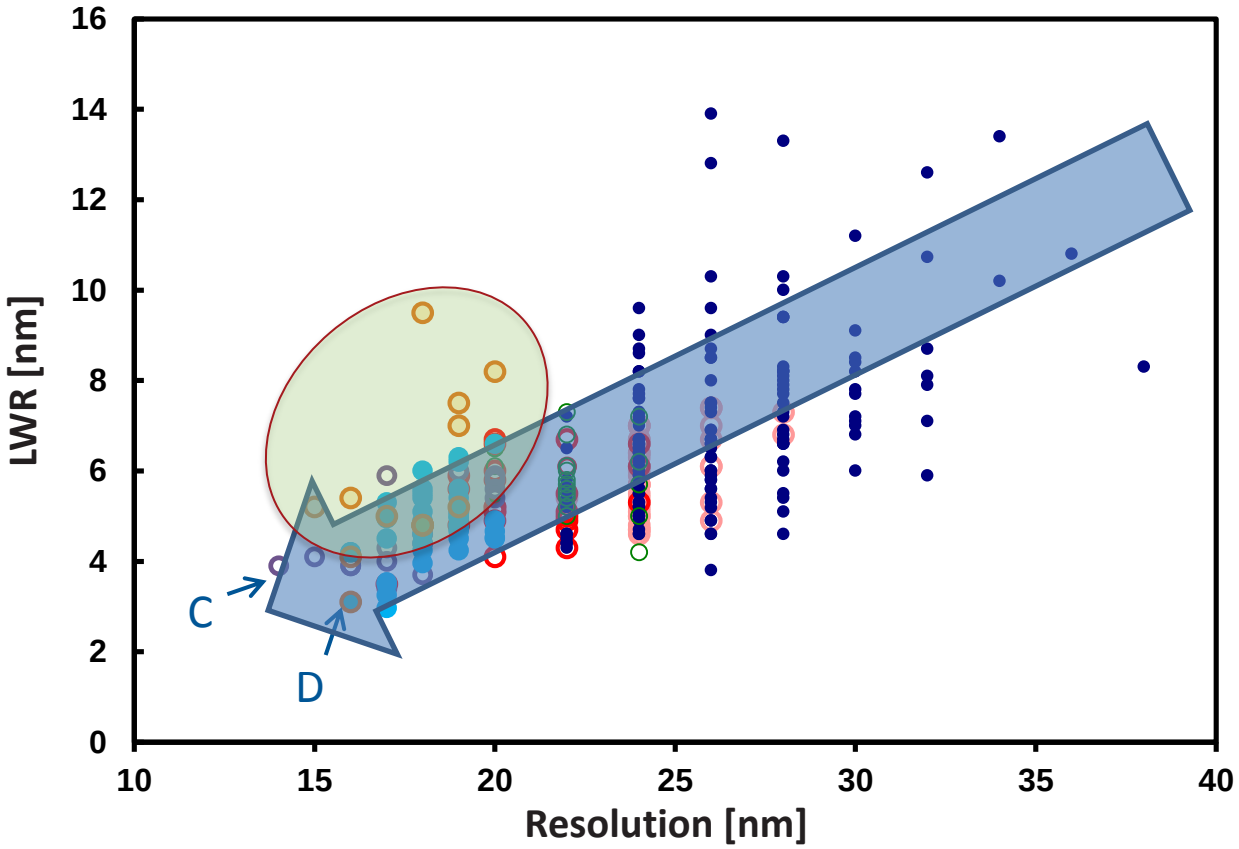


	A	B
Image		
Size	16nm HP	20nm HP
LWR	3.7nm	5.6nm
Speed	21.0mJ/cm²	8.8mJ/cm²

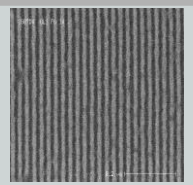
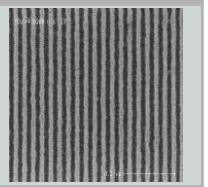
- **Resolution has trade-off with sensitivity as expected**
- **Higher photospeeds were observed in this LS evaluation, compared to previous test.**

EUV Resist Performance Status

LWR vs. Resolution



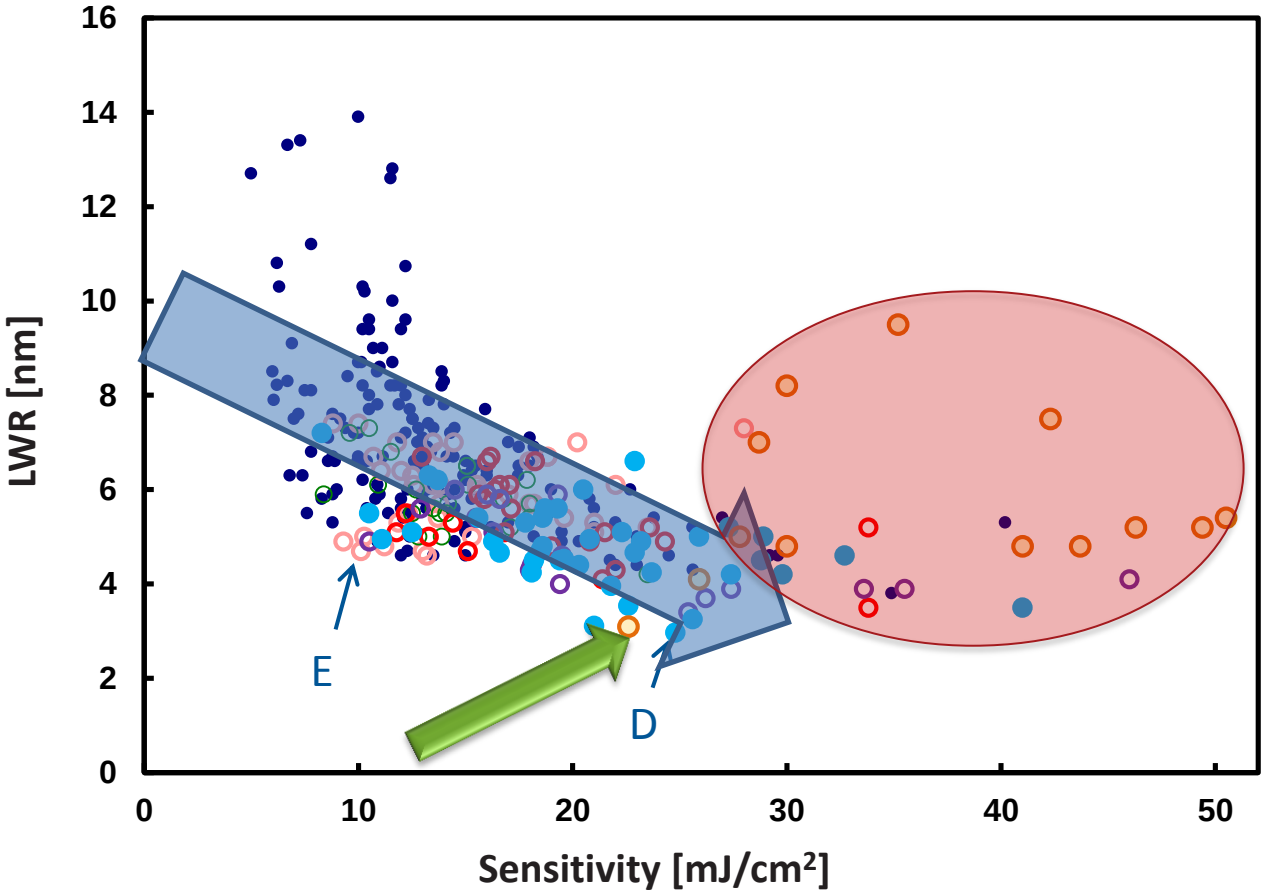
- ~2010
- 2011, Albany Quad
- 2011, Albany Dipole
- 2011, LBNL 18nm Dipole
- 2011, LBNL Pseudo PSM
- 2012, LBNL Pseudo PSM
- 2013, LBNL Pseudo PSM (new mask)

	C	D
Image		
Size	14nm HP	17nm HP
LWR	3.8nm	2.9nm
Speed	33.6mJ/cm^2	26.5mJ/cm^2

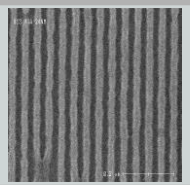
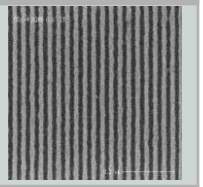
❑ **Lowest LWR is ~3nm : no progress compared to previous test**

EUV Resist Performance Status

LWR vs. Sensitivity



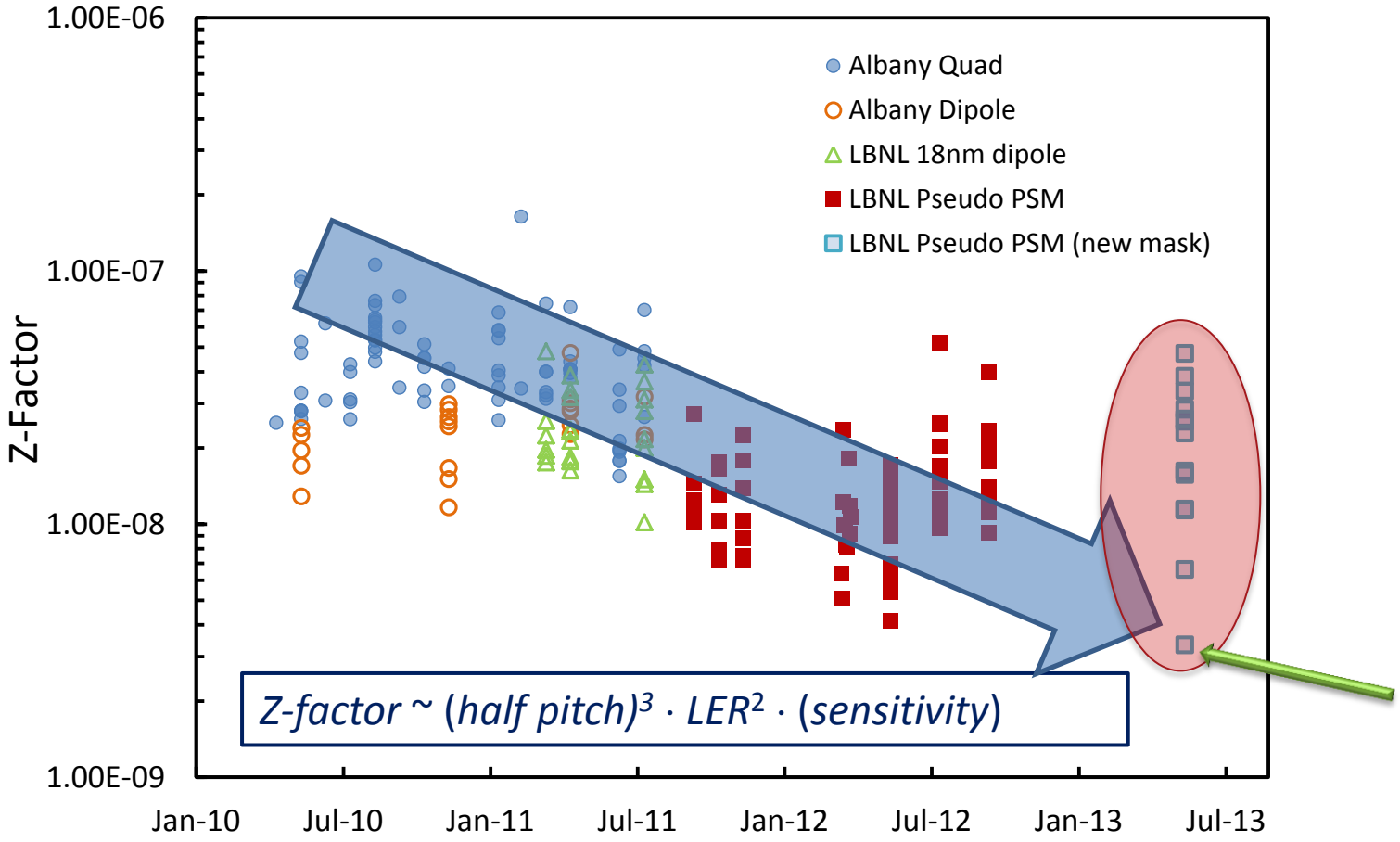
- ~2010
- 2011, Albany Quad
- 2011, Albany Dipole
- 2011, LBNL 18nm Dipole
- 2011, LBNL Pseudo PSM
- 2012, LBNL Pseudo PSM
- 2013, LBNL Pseudo PSM (new mask)

	E	D
Image		
Size	24nm HP	17nm HP
LWR	4.7nm	2.9nm
Speed	10.1mJ/cm²	26.5mJc/m²

- **Some resists in this evaluation show worse LWR with higher sensitivity, compared to previous test**
- **One resist show good LWR with good sensitivity**

Z-Factor of EUV Resists Over Time

Lines and Spaces



- **Data represent materials from six suppliers**
- **Only one material shows significantly improved Z-value**

Summary, Resist materials Evaluation

1. 13 of 18 resists passed 20nm hp screening.

2. One resist shows progress in improving Z-factor.

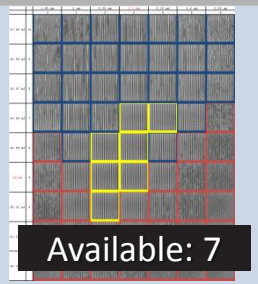
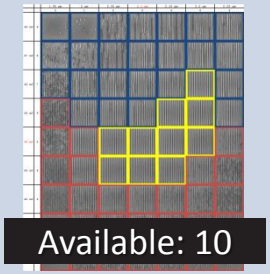
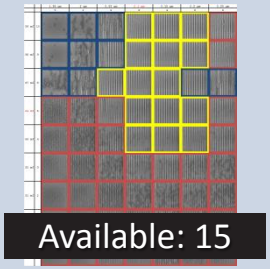
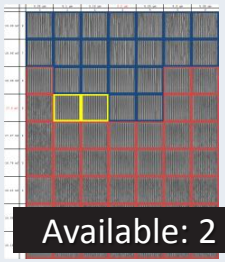
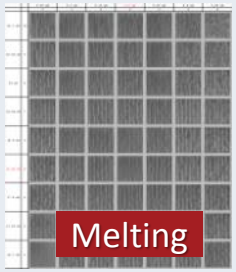
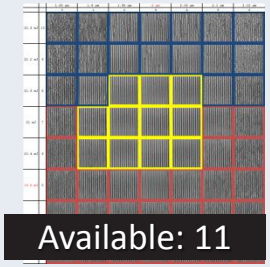
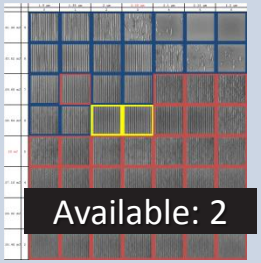
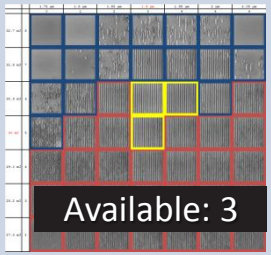
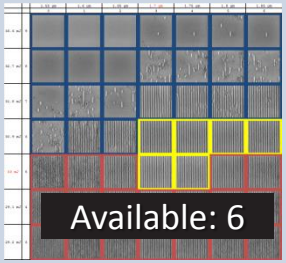
3. Some of resists show worse LWR even with higher sensitivity.

4. Resists were selected for further evaluation:
   - Outgas test – Passed
   - Defined 3 best resists from different companies
   - FIRM Rinse process with TEL and AZ

- **FIRM Rinse, Track Based Smoothing**

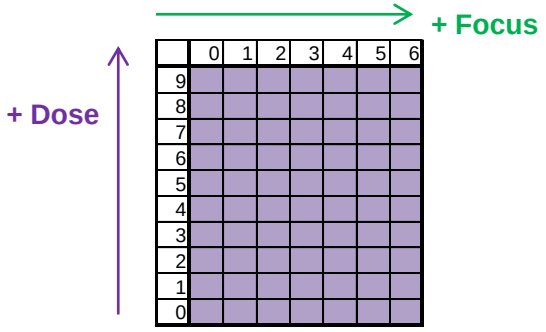
FIRM Compatibility, COL resists

- 55nm Resist thickness, Albany eMET @24nm

	DIW	Conv. FIRM	Alt. FIRM
Resist H	 Available: 7	 Available: 10	 Available: 15
Resist M	 Available: 2	 Melting	 Available: 11
Resist R	 Available: 2	 Available: 3	 Available: 6

Collapses / Peelings
No collapses
Severe bridges / Not resolved
Melted / Washed out

Exposure Field

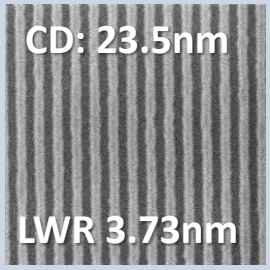
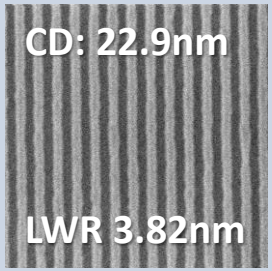
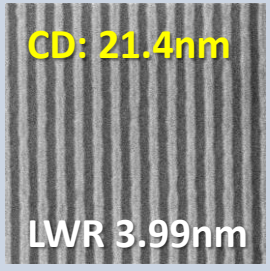
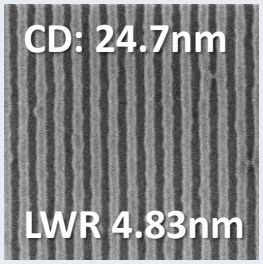
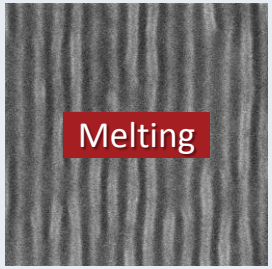
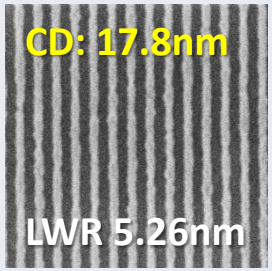
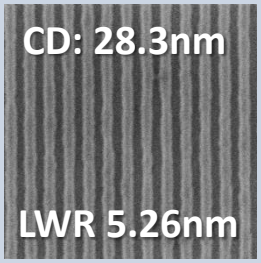
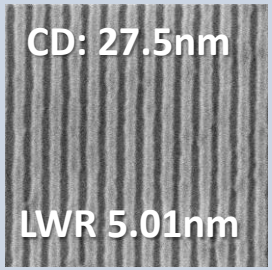
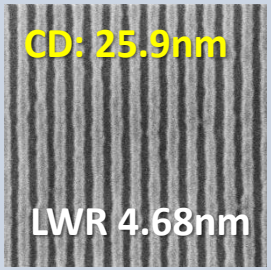


Resist: SEMATECH COL Resists
Target: 24nm (L/S)
Exposure: Albany MET
Illumination : Quadrapole
DEV : TMAH

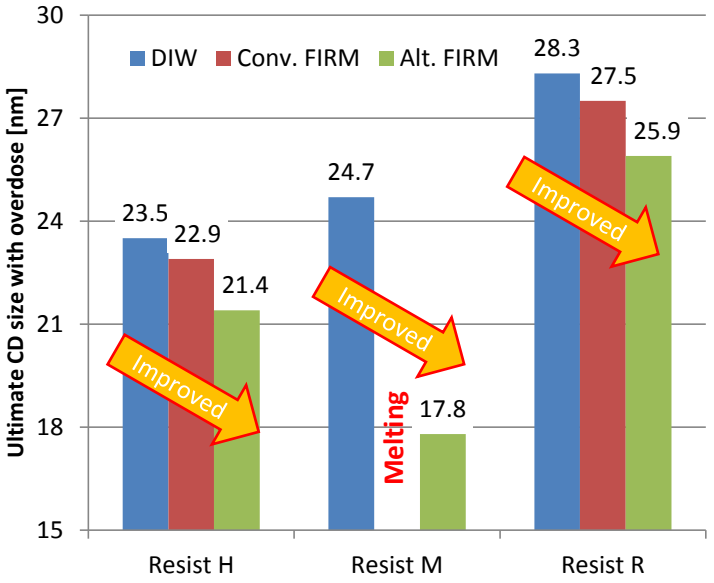
- **Alternative FIRM helps to maximize the available process window without melting patterns.**

Ultimate Resolution with Over Dose

- 55nm Resist thickness, Albany eMET @24nm

	DIW	Conv. FIRM	Alt. FIRM
Resist H			
Resist M			
Resist R			

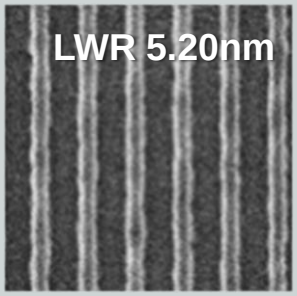
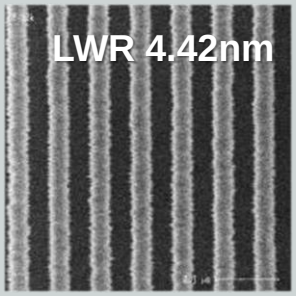
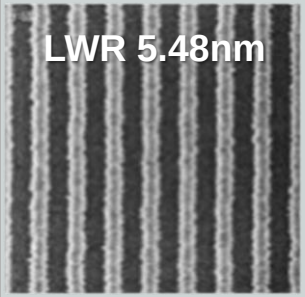
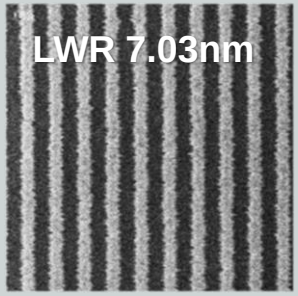
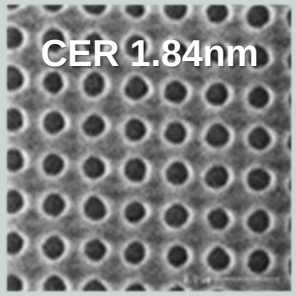
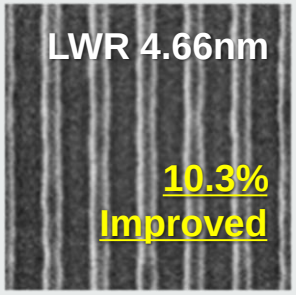
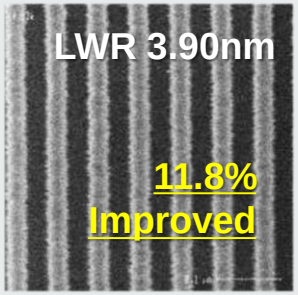
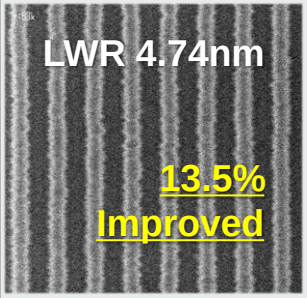
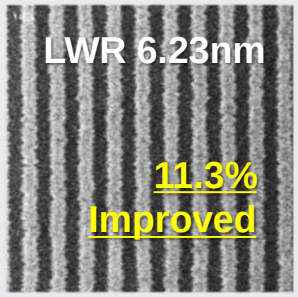
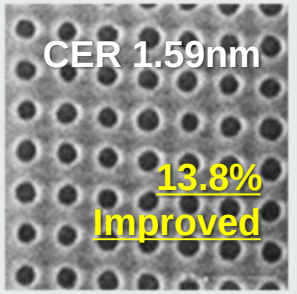
《CD at ultimate resolution》



- **By applying Alt. FIRM rinse the ultimate resolution is improved over using DIW or Conv. FIRM rinses.**

Smoothing Compatibility by Target Features

- Albany ADT, 5 kinds of features

	70nm pitch / lines	64nm pitch / lines	56nm pitch / lines	44nm pitch / lines	64nm pitch / contacts
Pre smoothing	 LWR 5.20nm	 LWR 4.42nm	 LWR 5.48nm	 LWR 7.03nm	 CER 1.84nm
Post smoothing	 LWR 4.66nm 10.3% Improved	 LWR 3.90nm 11.8% Improved	 LWR 4.74nm 13.5% Improved	 LWR 6.23nm 11.3% Improved	 CER 1.59nm 13.8% Improved

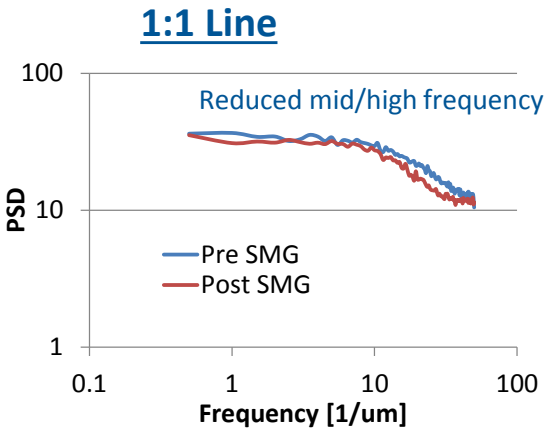
- **By using smoothing process several patterns were demonstrated to have LWR/CER improvement over several features.**

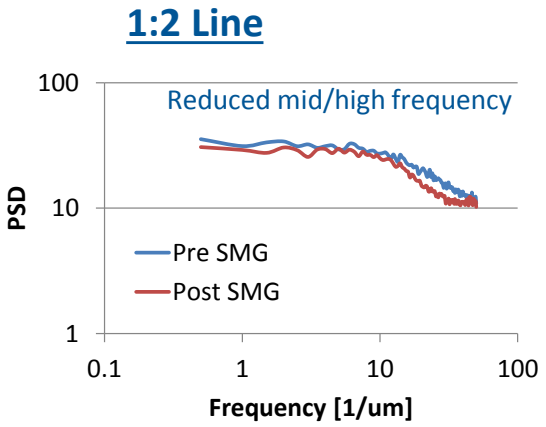
Smoothing Thru-pitch Dependency, LWR

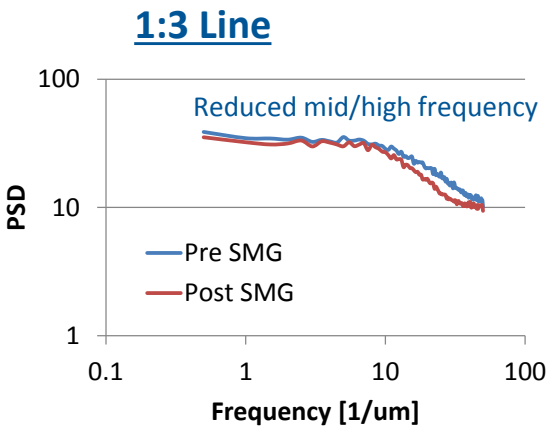
	Pre	Post
1:1 Line	CD : 34.40 LWR 4.95	LWR 9.7 % CD : 34.02 LWR 4.47
1:2 Line	CD : 35.75 LWR 4.55	LWR 9.9 % CD : 35.12 LWR 4.09
1:3 Line	CD : 35.03 LWR 4.82	LWR 11.4 % CD : 34.54 LWR 4.27
1:6 Line	CD : 33.04 LWR 4.80	LWR 11.0 % CD : 32.74 LWR 4.27

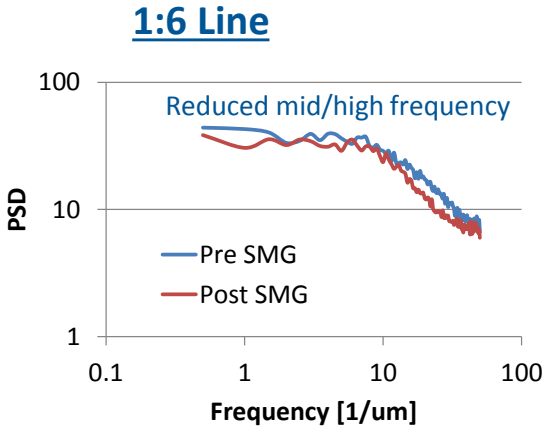
CD [nm] / LWR [nm]

- Albany ADT, SEMATECH Test Resist







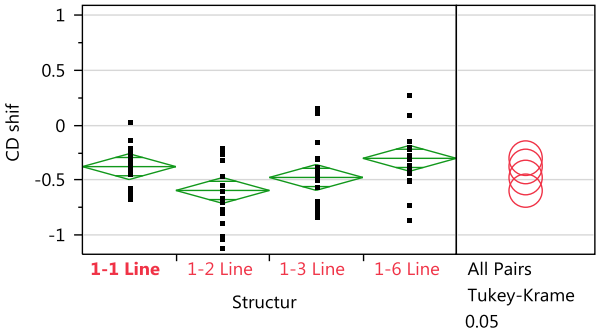


- **Track based smoothing resulted in approximately 10% LWR reduction even across multiple pitch ranges on the same wafer.**

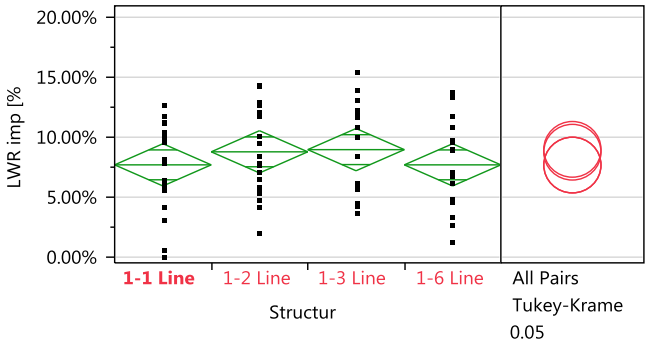
Smoothing Bias Study by Pitch

- Albany ADT, SEMATECH Test Resist

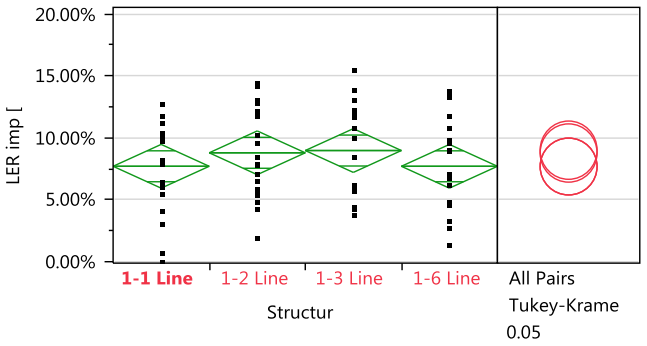
1) CD shift

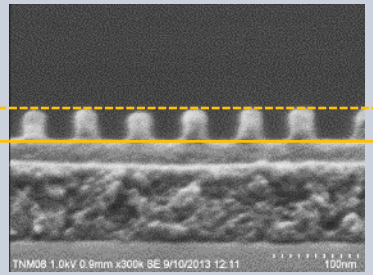
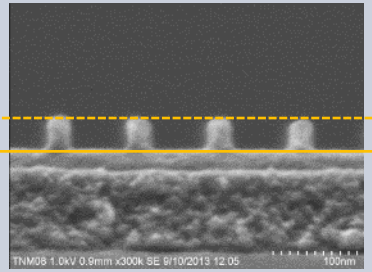
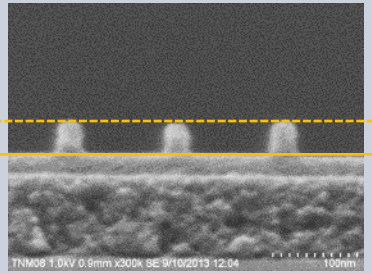
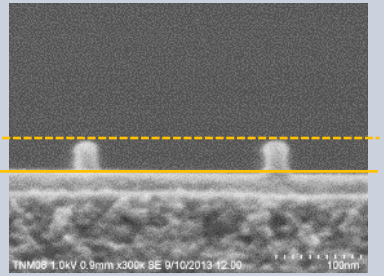


2) LWR improvement



3) LER improvement



	1:1 Line	1:2 Line	1:3 Line	1:6 Line
X-section				

- **Looking at the three parameters, there is no statistical difference with multiple targets. Also similar profiles are observed on 1:1 - 1:6 pitches from X-section.**

Summary, FIRM and Smoothing

1. The alternative FIRM rinse has been demonstrated to maximize the process window on 3 resists from the cycle of learning.

2. Track Based Smoothing has been confirmed to improve roughness across several pitches.

3. The Smoothing induced bias does not show any statistical difference thru pitches 1:1 – 1:6 on the same wafer.